

# Harmonic Minimization In Multilevel Inverters By Using PSO

<sup>1</sup>N. Prashanth, <sup>2</sup>B. Kumar, <sup>3</sup>J. Yadagiri, <sup>4</sup>A. Dasgupta

<sup>1</sup>PG Scholar, Electrical Engg., KIIT University Bhubaneswar, India  
prashanthkumar0228@gmail.com

<sup>2</sup>Lecturer, Electrical Engg, IGIT Sarang Bhubaneswar, India,  
brijesh\_elect@yahoo.co. in

<sup>3</sup>Assistant. Professor Electrical Engineering KIIT University Bhubaneswar, India  
giri055@gmail.com

<sup>4</sup>Professor, Electrical Engineering KIIT University Bhubaneswar, India  
adasguptafel@kiit.ac.in

**Abstract**— Harmonic Elimination in a multilevel inverters is an optimization problem which is solved by applying particle swarm optimization (PSO) technique. The derived equation for the computation of total harmonic distortion (THD) of the output voltage of the multilevel inverter is used as the objective function in PSO algorithm. The objective function used is to reduce the THD of the multilevel inverter and obtain the corresponding switching angles with the elimination of possible lower order harmonics. In this paper a pseudo code based algorithm is proposed to deal with inequality constraints which will help in accelerating the optimization process. The proposed method is applied for seven level cascade inverter to eliminate the 5<sup>th</sup> and 7<sup>th</sup> order harmonics to reduce the total harmonic distortion. This proposed PSO algorithm is effective in reducing the total harmonic distortion corresponding the range of modulation index. The simulation results show that the proposed PSO method is indeed capable of obtaining higher quality of solutions to eliminate 5<sup>th</sup> and 7<sup>th</sup> order harmonics and to reduce the total harmonic distortion of 7-level cascade inverter

**Keywords**— selective harmonic elimination (SHE), particle swarm optimization (PSO), Total harmonic distortion (THD)

## I. INTRODUCTION

Multilevel inverters have drawn tremendous interest in high power applications. It synthesizes a desired output voltage from several levels of dc voltages as inputs. By taking sufficient number of dc sources, a nearly sinusoidal voltage waveform can be synthesized [1]

To control the output voltage and reduce the harmonic distortion several methods have been presented. In those the mainly using methods are sinusoidal pulse width modulation and selective harmonic elimination method (SHE). The SHE method is a switching technique for which transcendental equations characterizing harmonics are solved to compute switching angles. It is difficult to solve the SHE equations as these are highly nonlinear in nature and may produce simple, multiple, or even no solutions for a particular value of modulation index. Iterative numerical techniques have been implemented to solve the SHE equations producing only one solution set, and even for this a proper initial guess and starting value of modulation index for which the solutions

exist, are required. The theory of resultants of polynomials and the theory of symmetric polynomials has been suggested to solve the polynomial equations obtained from the transcendental equations [4]. A difficulty with these approaches is that for several H-bridges connected in series, the order of the polynomials becomes very high thereby making the computations of the solutions of these polynomials very complex. Optimization technique based on Genetic Algorithm (GA) was proposed for computing switching angles for 7-level inverter. The implementation of this approach requires proper selection of certain parameters such as population size, Mutation rate etc, thereby its implementation becomes also difficult for higher level inverters [2]. To circumvent the above problems, in this paper we presented the application of PSO for solving these equations and obtain the harmonic distortion lesser compared to other techniques which are used in SHE method. This paper presents the analysis of 7-level cascaded inverter with three H-bridges, solution of three transcendental equations using PSO and elimination of lower order harmonics such as 5<sup>th</sup> and 7<sup>th</sup> order with minimum harmonic distortion and obtain desired fundamental voltage.

## II. CASCADED MULTILEVEL INVERTER

The cascade multilevel inverter consists of a series of H-bridge (single-phase full-bridge) inverter units. As stated above, the general function of the multilevel inverter is to synthesize a desired voltage from several separate dc sources (SDCSs) such as solar cells, fuel cells, ultra capacitors, etc. Fig. 1 shows a single-phase structure of a seven level cascade inverter with SDCSs. Each SDCS is connected to a single-phase full-bridge inverter and can generate three different voltage outputs,  $+V_{dc}$ , 0 and  $-V_{dc}$ . This is accomplished by connecting the dc source to the ac output side by using different combinations of the four switches and the ac output of each level's full-bridge inverter is connected in series such that the synthesized voltage waveform is the sum of all of the individual inverter outputs.

The number of output phase (line-neutral) voltage levels in a cascade multilevel inverter is then  $2S+1$ , where S is the

number of dc sources. For example the phase voltage output of seven level inverter as shown in Fig.2, there are three switching angles and three non-linear transcendental equations, where 's' is the number of H-bridges connected in cascade per phase[3]. Among s number of switching angles, generally one switching angle is used for fundamental voltage selection and the remaining (s-1) switching angles are used to eliminate certain predominating lower order harmonics. In three-phase power system with isolated neutral, triplen harmonics are cancel out automatically, and only non-triplen odd harmonics are present.

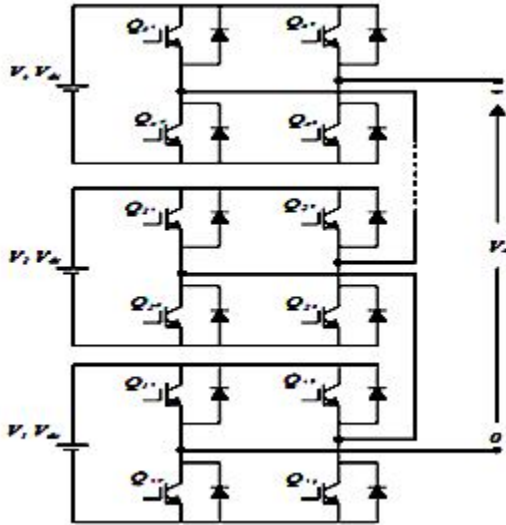


Fig.1.seven level cascaded inverter

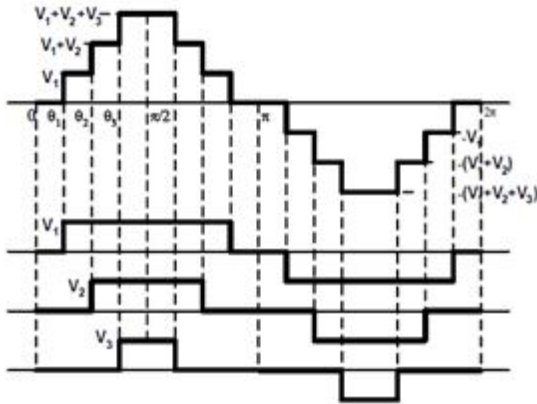


Fig.2 output voltage of 7-level cascade inverter

### III. HARMONIC MINIMIZATION ANALYSIS

The Fourier series expansion for the above stair case wave form is given below

$$V_{an}(\omega t) = \sum_{n=1,3,5,7}^{\infty} \frac{4V_{dc}}{n\pi} \left[ \frac{\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3)}{\cos(n\theta_3)} \right] [\sin(n\omega t)] \dots\dots (1)$$

The fundamental voltage is obtained from the calculated switching angles  $\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_n$  from equation(1). 'n' represents the order of the harmonics and the switching angles are equal to the number of dc-sources. It is required to find the switching angles in the range of 0 to  $\pi/2$  considering 5<sup>th</sup> and 7<sup>th</sup> order phase voltage to zero. For seven level cascade

inverter, the fundamental voltage in terms of switching angles is given in equation(2).

$$V_1 = \frac{4V_{dc}}{\pi} (\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3)); \dots (2)$$

The Modulation index is defined as the ratio of fundamental voltage ( $V_1$ ) to the maximum obtainable fundamental voltage ( $V_{1max}$ ). The maximum fundamental voltage is obtained when all the switching angles are zero and the  $V_{1max}$  is given as

$$V_{1max} = 3 * \left( \frac{4V_{dc}}{\pi} \right) \dots\dots (3)$$

Then the modulation index (M) is given as

$$M = \frac{V_1}{\left( 3 * \left( \frac{4V_{dc}}{\pi} \right) \right)} \dots\dots (4)$$

The 7-level cascaded inverter requires three H-bridges. The non linear equations which are used to finding the switching angles and desired fundamental voltage of 7-level inverter are equations(5),(6)and(7).

$$\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) = 3M \dots\dots(5)$$

$$\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3) = 0 \dots\dots(6)$$

$$\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) = 0 \dots\dots(7)$$

These are the non linear transcendental equations for eliminating lower order harmonics such as 5<sup>th</sup> and 7<sup>th</sup> order and get desired fundamental voltage[7]. For the given values of M (from 0 to 1), it is required to get complete and all possible solutions of these equations for determining the switching angles and lower THD.

### IV. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) refers to a relatively new family of algorithms that may be used to find optimal solutions to numerical and qualitative problems[6]. PSO was introduced by Russell Eberhart and James Kennedy in 1995 inspired by social behavior of birds flocking or fish schooling. It is easily implemented in most programming languages and has proven to be both very fast and effective when applied to a diverse set of optimization problem.

In PSO, the particles are "flown" through the problem space by following the current optimum particles. Each particle keeps track of its coordinates in the problem space, which are associated with the best solution (fitness) that it has achieved so far. This implies that each particle has memory, which allows it to remember the best position on the feasible search space that has ever visited. This value is commonly called *Pbest*. Another best value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the neighborhood of the particle. This location is commonly called *Gbest*. The basic concept behind the PSO technique consists of change in the velocity (or accelerat

ing) of each particle toward its  $Pbest$  and  $Gbest$  positions at each time step. This means that each particle tries to modify its current position and velocity according to the distance between its current position and  $Pbest$ , and the distance between its current position and  $Gbest$ . The position and velocity vectors of the  $i^{th}$  particle of a d-dimensional search space can be represented as  $X_i = (x_{i1}, x_{i2}, \dots, x_{id})$

and  $V_i = (v_{i1}, v_{i2}, \dots, v_{id})$  respectively. On the basis of the value of the evaluation function, the best previous position of a particle is recorded and represented as  $Pbest_i = (P_{i1}, P_{i2}, \dots, P_{id})$ . If the  $g^{th}$  particle is the best among all particles in the group so far, it is represented as  $Gbest = Pbest_g = (P_{g1}, P_{g2}, \dots, P_{gd})$ . The particle tries to modify its position using the current velocity and the distance from  $Pbest$  and  $Gbest$ . The modified velocity and position of each particle for fitness evaluation in the next iteration are calculated using the following equations

$$v_{id}^{k+1} = w \times v_{id}^k + c_1 \times rand_1 \times (Pbest_{id} - x_{id}^k) + c_2 \times rand_2 \times (Gbest_{gd} - x_{id}^k) \quad \dots (8)$$

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \quad \dots (9)$$

Here  $w$  is the inertia weight parameter, which controls the global and local exploration capabilities of the particle.  $c_1, c_2$  are cognitive and social coefficients,  $rand_1$  and  $rand_2$  are random numbers between 0 and 1. For the proposed method,  $c_1 = 2, c_2 = 2$ . A large inertia weight factor is used during initial exploration and its value is gradually reduced as the search proceeds. The concept of time-varying inertial weight (TVIM) is given by.

$$w = (w_{\max} - w_{\min}) \times \frac{iter_{\max} - iter}{iter_{\max}} + w_{\min} \quad \dots (10)$$

$$w_{\max} = 0.9; w_{\min} = 0.4$$

Where,  $iter_{\max}$  is the maximum number of iterations.

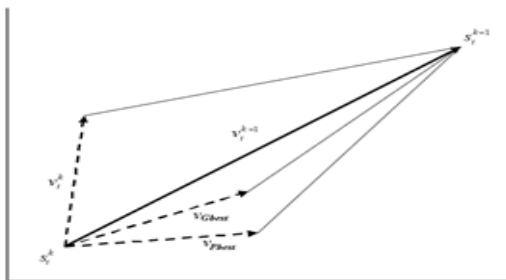


Fig.3.concept of modification of searching point

## V. THE PROPOSED PSO ALGORITHM

The minimization of THD in multilevel inverters is achieved by using this PSO algorithm because of its simple in nature and easy to implement, computational efficient. The procedure for getting optimized results the objective function is taken as the THD equation is as follows

$$\%THD = \frac{\sqrt{(V_2^2 + V_3^2 + \dots V_n^2)}}{V_1} \times 100 \quad \dots (11)$$

The proposed PSO algorithm is given as following steps:  
 Step1: create the random initial population size of switching angles by considering their limitation is 0 to  $\pi/2$   
 Step2: initialize the velocity, Pbest, Gbest, iteration count for computing switching angles  
 Step 3: update the iteration count  
 Step 4: update the velocity and position according to the equations (8) & (9) for moving of particles in search space  
 Step 5: evaluate the fitness or objective function by using equation (11)  
 Step 6: update the values of Pbest and Gbest  
 Step 7: Is criterion achieved then go for next step otherwise repeat the step3 to step6 for best solution  
 Step 8: select the best solution of fitness value.

In this process the maximum iterations are 100 and the population size is 20 and using the decreasing inertia function with initial weight of 0.9 and final weight of 0.4. This proposed algorithm is mainly used to minimize the total harmonic distortion for selected initial random switching angles. For getting lower value of total harmonic distortion and minimization of lower order harmonics the objective function is taken as a total harmonic distortion equation.

For every iteration the value of the THD is updated for their suitable best values by changing the velocity and position of the current particles. Similarly the values of switching angles also updated for optimum values to get lower value of THD

## VI. COMPUTATIONAL RESULTS

For seven level cascade inverter it is required to eliminate the 5<sup>th</sup> and 7<sup>th</sup> order harmonics and get the minimization in total harmonic distortion. The Fig.4 shows the comparison of Modulation Index Vs THD for 7-level Inverter in PSO method. From that we observed that where the Modulation Index is Increases then the total harmonic distortion is decreases to minimum value. The modulation index value is varies for the linear range from 0.1 to 0.9. The THD value is decreased from 21 to 5. The lowest THD value is occurred at 0.9 modulation index value. The Fig.5 shows the obtained switching angles corresponding with their Modulation index values. These results have been shown by using the curve fitting tool. The switching angles ( $\alpha_1, \alpha_2, \alpha_3$ ) are varies within the range of 0 to 90° only.

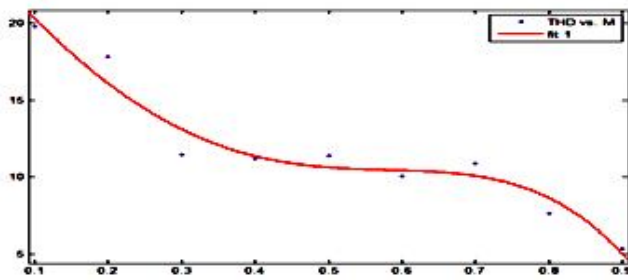


Fig.4 comparison of THD Vs Modulation Index for PSO

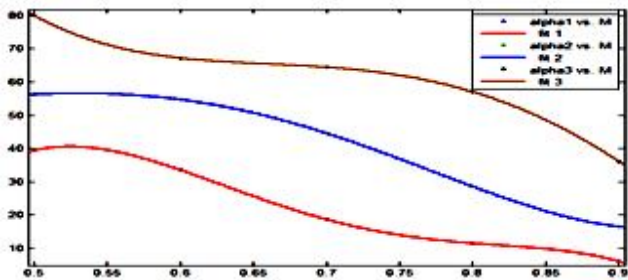


Fig.5 comparison of switching angles Vs Modulation Index

The Fig.6 shows the Harmonic analysis of 7-level cascade multilevel inverter for elimination of lower order harmonics such as 5<sup>th</sup> and 7<sup>th</sup> order. The arrow marks shown in Fig.6, shows the elimination of lower order harmonics in 7-level cascaded inverter. The Fig.7 shows the comparison of

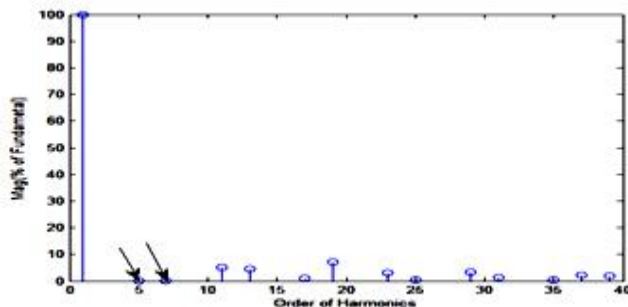


Fig.6 Harmonic Analysis for 7-level Cascade Inverter

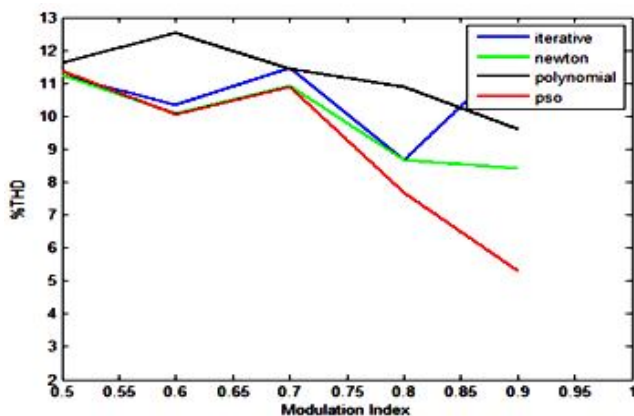


Fig.7 Comparison of THD Vs switching angles of different selective harmonic elimination methods

THD vs. switching angles of different programming methods and it also verify that the THD value of PSO method is less compare to the other programming methods. The value of THD for proposed method of PSO is 5 at modulation index

of 0.9. The remaining methods having the value of THD are above 10 at the higher modulation index. The proposed algorithm has the advantage to overcome the drawbacks of the programming methods

This proposed method is the fast convergence and it is easy to implement to get optimum values of desired output. Previous methods work has the complexity nature of solving the selective harmonic elimination equations and gives the slower convergence. This method uses the initial guess values and the objective function, to get the optimum values of switching angles and total harmonic distortion at the same time. The previous work of basic PSO has done the work on taking the objective function as to get the optimum values of switching angles [6]. The proposed PSO method eliminates the lower order harmonics and minimizes the harmonics up to 39<sup>th</sup> order of harmonics.

## VII. HARDWARE IMPLEMENTATION

The Hardware Implementation of 7-level cascade multilevel inverter requires three single phase full bridge inverters and for each bridge requires four IGBT's. The output of these three bridges is connected in series manner such that getting the desired stair case output voltage waveform for given input DC Sources. The output voltage wave form is approximately equal to the desired sinusoidal waveform. In this hardware implementation, we have used the PIC16F877A microcontroller programme to generate the gating signals to drive the IGBT's. In this PIC micro controller three ports are used for generating the gating signals

### A) The Components Required:

Serial No	Name of the Component	Quantity
1.	FGA25N120ANID 1200VNPT Trench IGBT	12
2.	Resistive load, 10Ω, 10W	01
3.	Gate Driving Circuits	12
4.	PIC Micro controller 16F877A	01
5.	Diodes FR304	12
6.	Connecting wires and vero board	

### B) Experimental setup:

The Fig.8 shows the experimental setup of 7-level cascaded multilevel inverter. In this the three H-bridges are used to construct the single phase 7-level cascaded inverter and each bridge is supplied by 5V as shown. The gate driving circuits are used to triggering the IGBT's. In this hardware implementation the 12 gate drive outputs are taken from gate drive circuit and given to each IGBT's of 7-level CSMLI. The PIC microcontroller is used to generate the triggering pulses for each switching device. This PIC microcontroller programme was loaded in to PIC16F877A chip by using the IC-Prog software. After loading the programme in to PIC chip the output of this chip is connected to the Gate driving circuits for giving gate pulses to all switching devices.



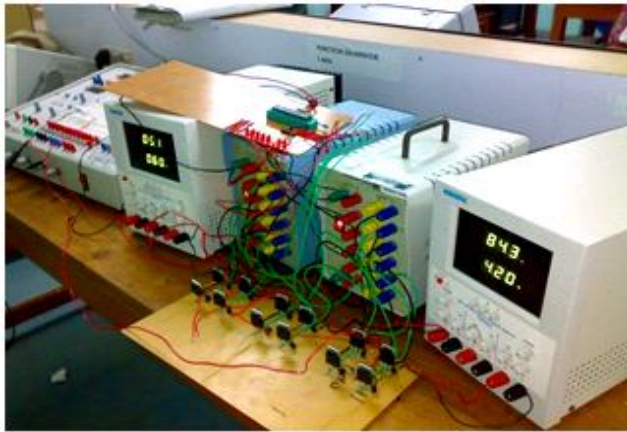


Fig.8 Experimental setup of single phase 7-level CSMLI

### C) Observations:

The input of the microcontroller is 5V and generation of triggering pulses from microcontroller is shown in Fig.9.

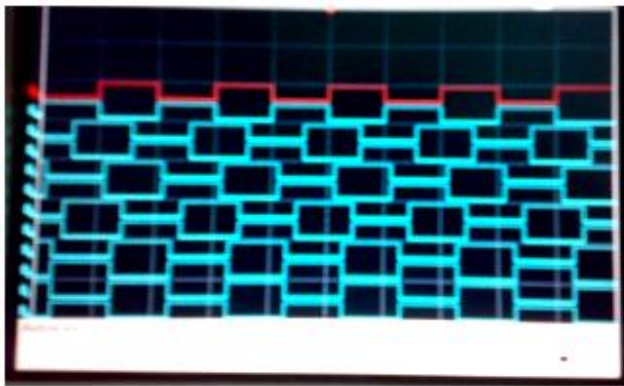


Fig.9 Triggering pulses from the PIC micro controller



Fig.10 Output Voltage Waveform of 7-level CSMLI from CRO

The given input DC-voltage of each bridge is 5V, thus the total input voltage of 7-level inverter is 15V. The FFT analysis of output voltage waveform is shown above Fig.12. The output voltage waveform obtained in the CRO is shown in Fig.10 and this waveform is loaded in the computer through software called SW206 signal analyzer to perform the FFT analysis. Fig.12 shows the FFT analysis and the amplitudes of their corresponding frequencies. Fig.11 shows the output voltage waveform of single-phase 7-level inverter using SW206 signal analyzer. The comparison of harmonic patterns between simulation and hardware for the modulation index of 0.9 is shown in Fig.13. The %THD of the hardware is 27.30%

whereas %THD of simulation is 15.37%. The total harmonic distortion is different for both simulation and hardware due to blanking time of 7 micro sec provided to the H-bridges.

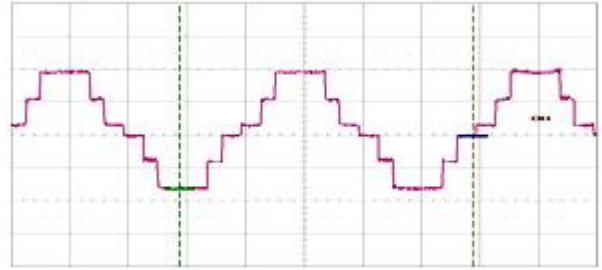


Fig.11 output voltage waveform of single phase 7-level CSMLI

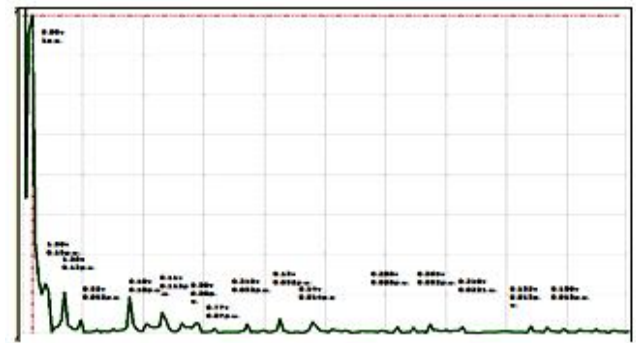


Fig.12 FFT analysis of output voltage, single phase 7-level CSMLI

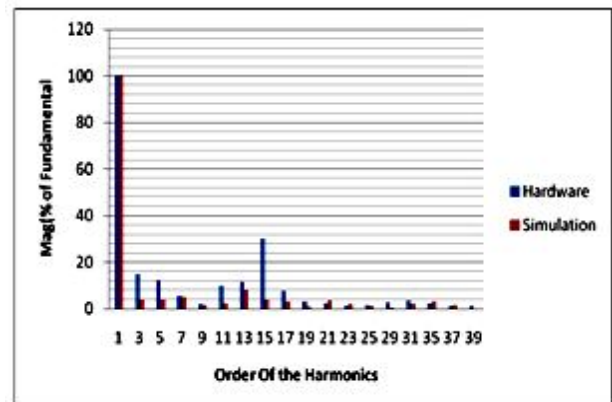


Fig.13 Comparison of harmonics spectra for Hardware and simulation results (Modulation Index 0.9)

## VIII. CONCLUSION

The selective harmonic elimination method can be used to eliminate the lower order harmonics and reduce the total harmonic distortion. The PSO method gives the lower %THD compared to the other classical iterative methods. In recent years the strategy for elimination of harmonics in multilevel Inverters by using PSO method has been done by taking better switching angles as the objective function. In this work lower order harmonics have been eliminated by using the equation for THD as the objective function and have given better results in minimization of THD for up to the 39<sup>th</sup> order of harmonics.

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